

continent where meteorological conditions can be more profitably studied, leading as they do to such far-reaching results.

It happens that within the past five years there have been marked examples of extreme types of both dominant anticyclonic and cyclonic conditions in these high latitudes. In December, 1917, the anticyclone was dominant in northwestern America. In December, 1918, it was the cyclone which dominated and southerly and southwesterly winds prevailed through the Canadian and American west even to the Great Lakes.

In view of the facts I have outlined, it appears to me to be desirable that the number of stations in the Arctic Zone should be augmented. The existing Alaskan stations are admirably situated, but another station at Point Barrow would be a great acquisition. A few stations in northeastern Siberia would be most instructive and one hopes that their establishment will not be long delayed. Canada, as before stated, will this coming summer place wireless stations at a few points in the valley of the Mackenzie River and one hopes that a couple of stations in Baffin land will be in existence within a year or so. The North American stations will then link up well with the Danish and Norwegian stations of Green-

land, Jan Mayen, Spitzbergen, and others, thus affording splendid data for investigating changes in the polar front.

While advocating an increase in the number of meteorological stations in high latitudes, I am not unmindful of the fact that a meteorological survey of the Pacific Ocean with its varying currents and temperatures may be even more important than a land survey, as the variation in the intensity of Pacific cyclones may depend largely on variations in ocean temperatures.

Assuming now that the great importance of stations in the far northwestern portions of North America has been demonstrated, we might with perhaps equal certainty show that wireless stations on Hudson Bay and in Baffin land would be most useful. When great anticyclones come in over western America their dominating influence is usually lessening as they spread toward the Atlantic coast, and we find that some of the coldest waves in eastern Canada accompany high areas coming in over Labrador, which high areas develop over the northeastern, not the northwestern, portion of the continent; and again these Hudson Bay and Labrador high areas represent the conditions under which Atlantic coast depressions are apt to develop, and moving northeast give severe storms along the Atlantic steamship routes.

FREQUENCY DISTRIBUTIONS OF DAILY AND HOURLY AMOUNTS OF RAINFALL AT GALVESTON, TEX.

By I. R. TANNEHILL, Meteorologist.

(Weather Bureau, Galveston, Tex., December 15, 1922.)

The rapidly-increasing use of rain insurance invites attention to the frequency distribution of rainfall. There has been considerable discussion of this subject in recent years and little hope is offered for a mathematical solution. Frequency polygons and other graphical solutions have been presented and these are valuable in that they disclose certain peculiarities in the frequency distribution of rainfall, perhaps local, which must be taken into account in any complete description of the climate and which would otherwise escape attention.

One of these peculiarities is the skewness or asymmetry of rainfall distributions.¹ The study of a series of rainfall-frequency polygons shows that the distribution of annual amounts does not conform to the law of errors;² that negative departures occur somewhat more frequently than positive and that the amount occurring with the greatest frequency is less than the mean. In consideration of monthly amounts it is found that the distribution is less symmetrical and may be multimodal.³ The frequency distribution of daily amounts bears no resemblance to the normal or Gaussian distribution of errors. It is best represented by a J-shaped curve.

Thus, we find that shortening the period of time in which the individual amounts fall apparently increases the skewness or asymmetry of the distribution.

Therefore the problem that confronts the insurance company in the establishment of rates for rain insurance is the most difficult, since hourly and daily amounts are insured against and chiefly the former.

We may obtain an average value of rain frequency for either the day or the hour in any given locality. In the long run these averages will be borne out approximately. Rain insurance is not issued for all hours of the day and night with the same frequency, nor for all seasons with

the same frequency, and therefore the averages or means are not trustworthy.

Again, all amounts of rain are not insured against. The policies usually limit the amounts to 0.10 inch or more, or to 0.20 inch or more. Another artificial limit has been introduced which greatly complicates the problem.

In preparing a table of premium rates for rain insurance the insurer depends upon the records of the Weather Bureau. Rain data are usually in the form of means and totals together with rather limited information concerning the frequency of certain extremes or excessive amounts. Because of the fact that the distributions of rain frequency are unsymmetrical in monthly and annual amounts and altogether asymmetrical in daily and hourly amounts, these means are of doubtful value in determining the probability of occurrence of certain amounts.

For example, the Weather Bureau computes a normal fall of rain for each day in the year. This amount may be, say, 0.12 inch for January 1 in a given locality. This value, 0.12 inch, is of no particular value in determining the probability of rain on January 1. At Galveston the normal for January 1 is 0.15 inch. In the 50 years this station has been in operation, the amount 0.15 inch has never occurred on January 1.

It would be possible to compute a normal fall for each hour of the year. Such a value would have no particular use. How, then, is the insurer to arrive at any trustworthy conclusion as to the amount or amounts likely to occur with the greatest frequency and how is he to determine the frequency with which a certain amount will be exceeded?

Rate tables have been issued, however, and one company states that rain insurance is being written almost as freely as fire insurance. Apparently these rates are based upon the frequency of days with 0.01 inch or more of precipitation.

In the following, the frequency of daily and hourly amounts of precipitation will be discussed with reference to Galveston, Tex., in the attempt to show that the aver-

¹ Tolley, Howard Ross: Frequency Curves of Climatic Data: MO. WEATHER REV., November, 1916, 44: 634-642.

² Marvin, Charles Frederick: Elementary Notes on Least Squares, the Theory of Statistics and Correlation for Meteorology and Agriculture, MO. WEATHER REV., October, 1916, 44: 551-599.

³ Weeks, John R.: Climate of Einghamton, N. Y., shown by the Histogram Method: MO. WEATHER REV., February, 1921, 49: 53-62.

age frequency of any amount is not a reliable basis for determination of such rates and that the insurer must take into consideration at least three facts: (1) That the frequency distribution of daily and hourly amounts is asymmetrical and that the mean is therefore not altogether trustworthy; (2) that mean rain intensity varies with time and place and therefore the frequency of any given amount of rainfall is not a reliable indication of the frequency of any other amount; (3) that rain frequency exhibits a decided daily march at Galveston and other places and that the maximum frequency may be five times or more in excess of the minimum.

In the REVIEW for February, 1921, will be found the frequency distributions of monthly rainfall at Binghamton, N. Y.³ These histograms are characteristic of daily rainfall. The frequency curve best fitting these data has been described as of the J-shape, though the curve which fits the frequency distribution of various percentages of cloudiness is more nearly the J-shape.

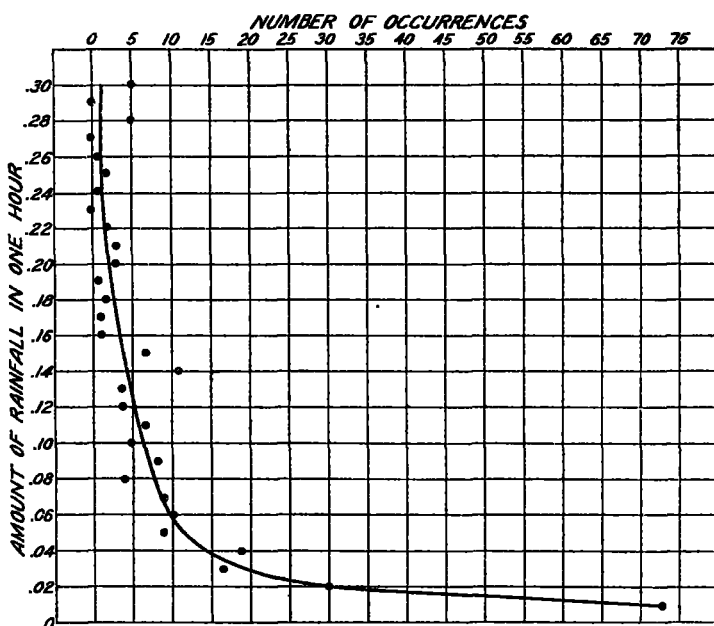


FIG. 1.—Frequency distribution of hourly amounts of rainfall at Galveston, Tex., during the year 1921. Mean of measurable hourly amounts was 0.14 inch. Curve fitted approximately.

In Figure 1 is shown the frequency distribution of hourly amounts of rainfall at Galveston, Tex., during the year 1921. Though this is a short period used in the grouping, the distribution approximates the form of the daily distribution. In this figure a total of 244 values were grouped up to and including 0.30 inch. The mean of all hourly falls, totaling 285, is 0.14 inch. There were 11 departures equal to the mean, or with a departure of zero. Only 26 per cent of all departures were positive. This distribution does not include the number of occurrences of a "trace" of rainfall nor of hours with no rain, the latter two classes totaling more than 8,000.

It is apparent that the mean hourly or mean daily rainfall is of no value in determining the probability of rainfall on any particular day or in any stated hour.

Table 1 shows the average number of days in a month at Galveston, Tex., with 0.01 inch or more, 0.04 inch or more, 0.25 inch or more, and 1 inch or more, for summer and winter months, roughly. This covers the 50-year period of observation at Galveston.

TABLE 1.

Month.	Average number of days with—			
	0.01 inch or more.	0.04 inch or more.	0.25 inch or more.	1 inch or more.
June, July, August, and September.....	8.7	7.0	3.7	1.3
November, December, January, February, and March.....	9.2	6.6	3.1	1.0

It will be noticed that there is a greater frequency of days with 0.01 inch or more in November to March, inclusive, but that the summer months show a greater frequency of the larger amounts. Therefore insurance rates based on the number of days with rainfall 0.01 inch or more for the several months will be in error because of the greater average rain intensity at some seasons than others.

One insurance company now makes a rate for insurance against amounts of 0.20 inch or more at Galveston in the month of November \$4.98 per \$100 and in February \$5.53 per \$100. This is evidently based on frequency of days with 0.01 inch or more rainfall.

Yet the 50-year record at Galveston indicates that, though 0.01 inch or more fell on 398 days in November and 467 days in February, there were only 133 days with 0.25 inch or more in February against 165 days in November. That this is the case is indicated in Table 1, showing that it is not fortuitous but is a characteristic of the season. The average rain intensity in November is greater than in February.

Thus we can not accept the average daily or average hourly fall as a criterion. Such averages are practically worthless because of the asymmetry of daily and hourly rainfall distributions. Information as to the frequency of certain amounts is required.

Though we have tabulated the frequency of days with 0.01 inch or more, 0.04 inch or more, 0.25 inch or more, and 1 inch or more, these data are insufficient. The frequency of any one of these amounts is not a reliable indication of the frequency of any other amount. If we are concerned with the frequency of hourly or daily falls of 0.10 inch or 0.20 inch we must determine these facts directly and not by assumption.

Figure 2 shows the frequency of amounts of 0.01 inch or more at Galveston, Tex., for each hour during the months June, July, August, and September in the 10 years 1913 to 1922, inclusive. There is a very pronounced daily march of rain frequency. The horizontal line at frequency of 44 represents the average of hourly frequencies. It will be seen that rain frequency at hours usually named in policies is considerably less than the average and therefore considerably less than would be indicated by consideration of the average number of days with 0.01 or more.

The causes of this variation of rain frequency were explained in the MONTHLY WEATHER REVIEW for September,⁴ 1921, where a similar daily march of rain frequency at Corpus Christi was discussed. There it was shown that the daily rise of the sea breeze about noon is sufficient to suppress convection. The mean hourly wind movements at Galveston are also shown in Figure 2, indicating that the reduction in rain frequency in the afternoon is due to increased wind movement. Attention is invited to the fact that both at Galveston and

³ Weeks, John R.: Climate of Binghamton, N. Y., shown by the Histogram Method; Mo. WEATHER REV. February, 1921, 49: 53-62.

⁴ Tannehill, I. R.: Wind Velocity and Rain Frequency on the South Texas Coast; Mo. WEATHER REV., September, 1921, 49: 498-499.

Corpus Christi the frequency of rain begins to decrease when the wind movement has reached a value approximately 12 to 13 miles per hour.

Figure 3 shows the daily march of rain frequency during the months of November, December, January, Feb-

Thus it will be seen that the average number of days with 0.01 inch or more gives no indication of the relative frequencies of hourly amounts in summer months in the afternoon and early evening, for which hours rain insurance is usually issued.

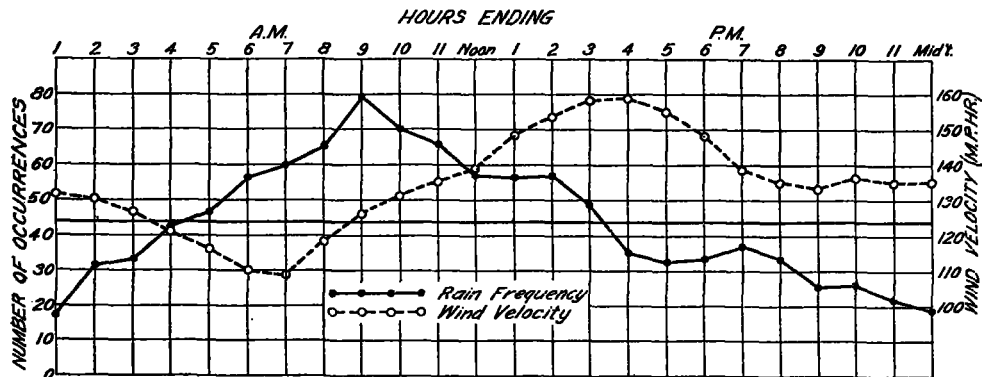


FIG. 2.—Mean hourly wind velocity, Galveston, Tex., June, July, August, and September, 1913-1922, inclusive, and number of occurrences of rain, 0.01 inch or more, June, July, August, and September, 1913-1922, inclusive.

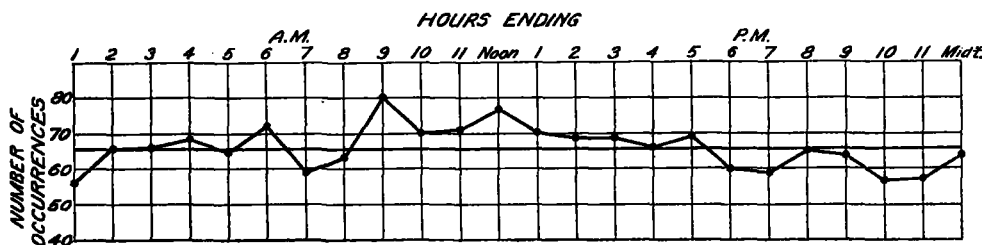


FIG. 3.—Hourly frequencies of 0.01 inch or more rainfall in months of November, December, January, February, and March, for 10-year period, November, 1912, to March, 1922.

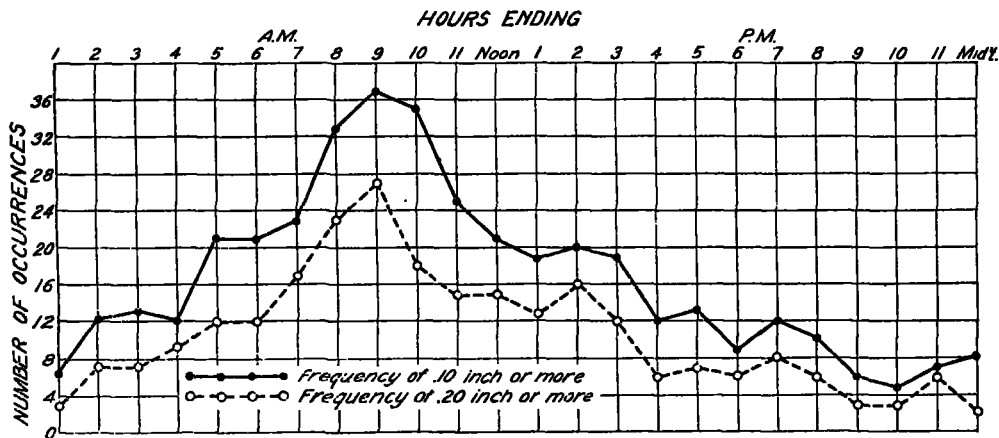


FIG. 4.—Number of occurrences of rainfall of amounts 0.10 inch or more, and 0.20 inch or more, during months of June, July, August, and September, from 1913 to 1922, inclusive.

ruary, and March. Occurrences of 0.01 inch or more in those months during 10 years, November, 1912, to March, 1922, inclusive, were tabulated by hours. It will be noticed that there is a rather poorly defined daily march with the maximum frequency about 9 a. m. The average hourly frequency of 66 for that period is shown by the horizontal heavy line. During the early evening there are slightly lower rain frequencies than the average.

The error in this assumption is, however, somewhat more aggravated than these figures would indicate. The amounts insured against are usually 0.10 inch or 0.20 inch. Figure 4 shows the hourly march of rain frequency during months of June, July, August, and September for the years 1913 to 1922, inclusive, and the values charted were 0.10 and 0.20 inch or more. It will be seen that the march of hourly frequencies of 0.10 inch

or more and 0.20 inch or more is even more pronounced than that of 0.01 inch or more.

To illustrate this point, see Figure 5. The mean frequencies for the day for each amount, 0.01 inch, 0.10 inch, and 0.20 inch are shown as 100 per cent, and the hourly frequencies are shown in percentage of the average. By this means it is easily seen that the amplitude of the daily variation is greater for the larger amounts.

If we use the number of days with 0.01 inch or more in a month as an indication of the frequency of 0.20 inch or more in any period for which insurance is to be issued, we are assuming that the hourly frequency is a straight line as represented by 100 per cent in Figure 5, whereas

the frequencies at 9 a. m. and 9 p. m. differ by more than 200 per cent.

In conclusion, it is evident that we can determine the frequency of any given amount in any stated period in only one way and that is by considering the individual occurrences of that amount in the stated period and grouping these values about a mean. There is a growing need for information of this character, both for rain insurance and for agricultural purposes. It is clearly evident that averages and means for rainfall data are not trustworthy as an indication of future occurrences.

Studies of this character bring to light certain peculiarities in the distribution of rainfall locally, not otherwise suspected.

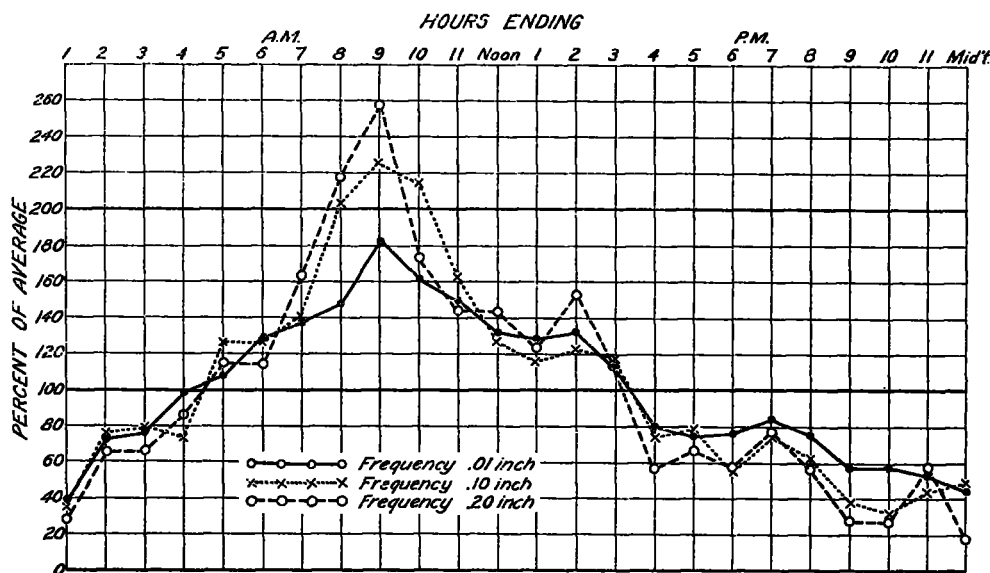


FIG. 5.—Hourly frequencies of 0.01 inch, 0.10 inch, and 0.20 inch, expressed as percentage of the average hourly frequency.

LOWERING OF KANSAS RIVER CHANNEL AT TOPEKA, KANS.

By S. D. FLORA, Meteorologist.

[Weather Bureau, Topeka, Kans., October 12, 1922.]

The frequent occurrence of record-breaking low stages in the Kansas River at Topeka without any apparent cause in the way of diminished precipitation in the drainage basin of the stream led to an investigation which seems clearly to show a lowering of the river channel of about a foot in the past 5 years and slightly more than 3 feet in the 18 years since the record was begun. Only stages for the 6 warm months, April to September, inclusive, of each year were considered in the investigation, as the record is not complete for all winter months.

Two methods were used in this study. The first was the utilization of a "floating" 5-year average—that is, by obtaining the average stages for successive 5-year periods from the beginning of the record and plotting them. (See fig. 1.) The second was the construction of a trend from a formula in use by statisticians, which has the advantage of making it possible to plot the change from the first year of the record to the last. (See fig. 2.) The graph representing this trend was obtained by means of the accompanying table.

It is interesting to note that the two methods corroborate each other closely. Figure 1 shows a lowering of the stage of 1.2 feet in the last 5 years of the record and Figure 2 a lowering of 0.95 feet, while from 1909—the first year for which a 5-year mean is available—to 1922

the change is 2.80 by Figure 1 and 2.66 by Figure 2. The straight-line trend extended to the first year of the record shows a total lowering of 3.42 feet in the stream channel in the 18 years under discussion.

Table showing trend of river stages at Topeka, Kans.

A. Year.	B. Average gauge height.	C.	D.	E.	F.
1905.....	9.5	-17	-161.5	289	8.78
1906.....	7.6	-15	-114.0	225	8.57
1907.....	6.7	-13	-87.1	189	8.38
1908.....	10.4	-11	-114.4	121	8.19
1909.....	8.1	-9	-75.6	81	8.00
1910.....	7.8	-7	-51.6	40	7.81
1911.....	6.1	-5	-32.0	25	7.62
1912.....	7.0	-3	-21.0	9	7.43
1913.....	5.3	-1	-5.3	1	7.24
1914.....	5.5	1	5.5	1	6.96
1915.....	11.1	3	33.3	9	6.67
1916.....	6.9	5	34.5	25	6.48
1917.....	5.8	7	40.6	49	6.29
1918.....	4.9	9	44.1	81	6.10
1919.....	7.5	11	82.5	121	5.91
1920.....	5.7	13	74.1	169	5.72
1921.....	5.5	15	82.5	225	5.53
1922.....	4.9	17	83.3	289	5.34
Sum.....	126.9		-185.1	1,938	
Average.....	7.05				

1938+2=969,
-185.1+969=-.19--yearly change trend.